Using CYGNSS to study MJO convection

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Background

One of the most distinctive signals of the Madden-Julian Oscillation (MJO) is the upscale development and organization of convection in the Indian Ocean.

Dynamics of the MJO (DYNAMO) campaign occurred in late 2011 – early 2012 to investigate this genesis stage. One of the best non-satellite wind datasets ever obtained over the ocean.

The Cyclone Global Navigation Satellite System (CYGNSS) mission can exploit this dataset to better understand the performance of the satellite constellation in regions of deep convection, in particular for characterizing the MJO.

Three Scientific Objectives

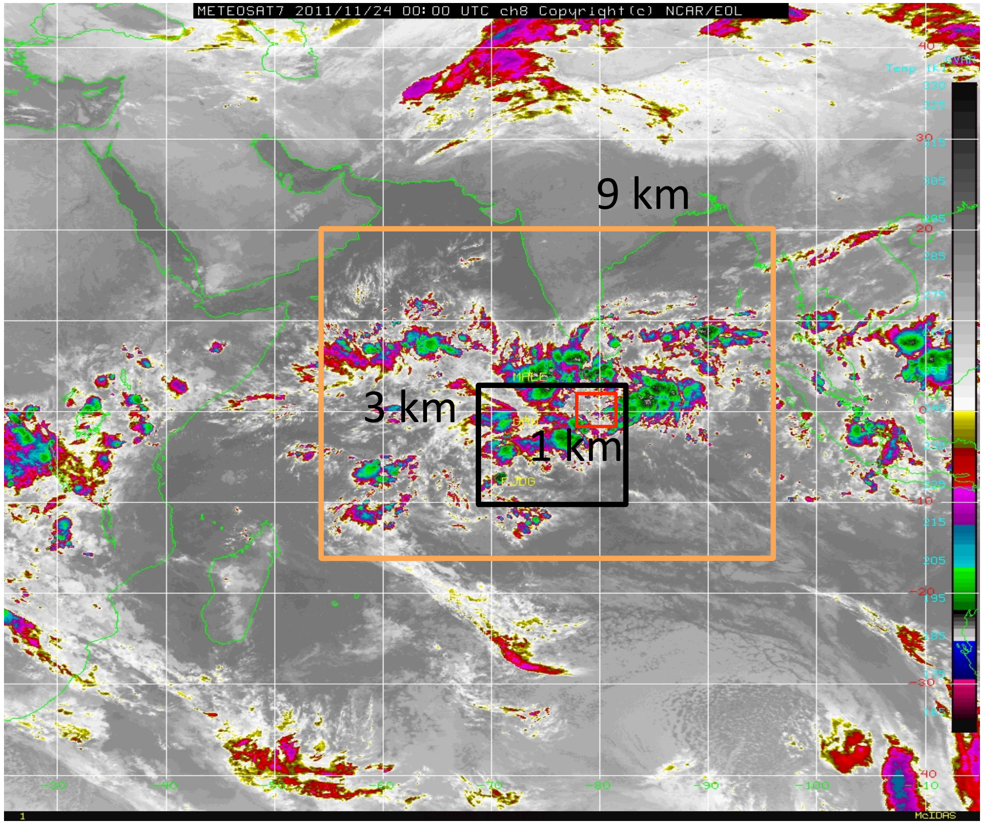
1. Produce a high-resolution surface wind dataset for multiple MJO onsets using WRF-assimilated winds and other data from DYNAMO.

2. Use the DYNAMO datasets, along with available scatterometer observations, to study the causes and impacts of wind variability at spatial and temporal scales finer than those planned to be provided by CYGNSS, and the implications of these processes for CYGNSS observations.

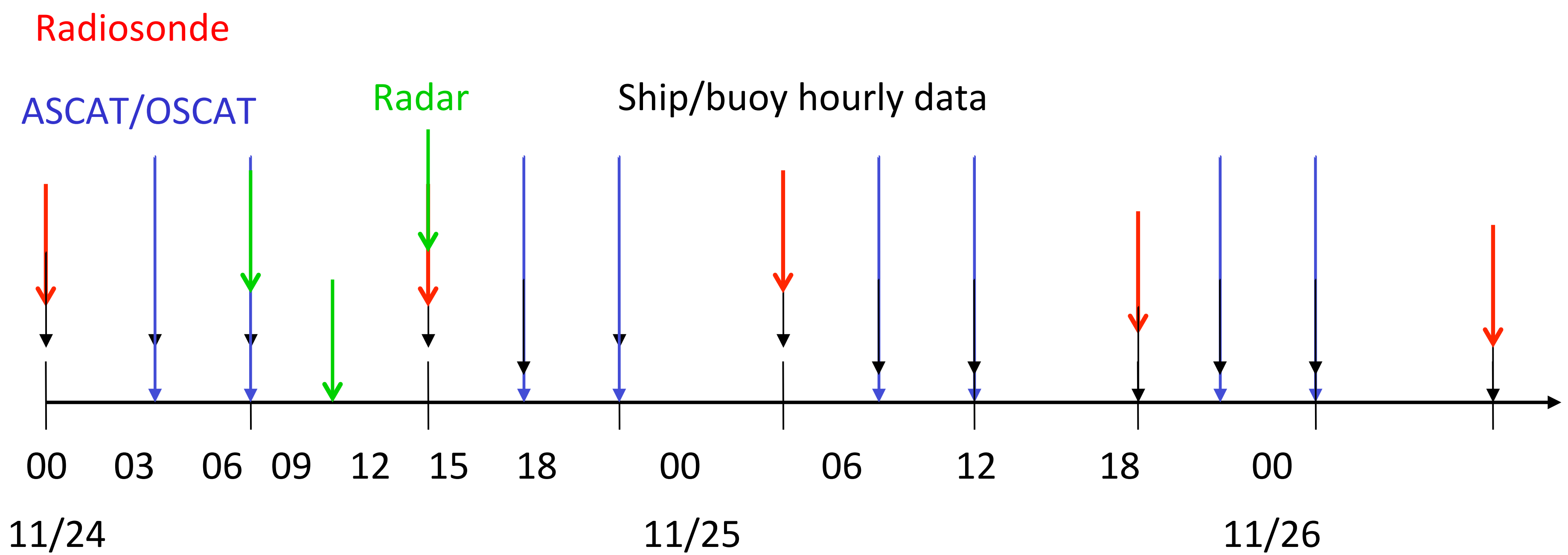
3. Using a simulated CYGNSS dataset for the MJO, perform observing system simulation experiments to determine the benefits of CYGNSS for improving scientific understanding and forecasting of the MJO, particularly its genesis over the Indian Ocean.

WRF Model Setup

- Advanced Research WRF
- A: 9-km resolution Indian Ocean domain
- B: 3-km DYNAMO quadrilateral domain
- C: 1-km high-resolution domain focused on Revelle
- 40 sigma levels (more levels in lower troposphere)
- Can do nested 9-3-1 km runs, plus separate runs

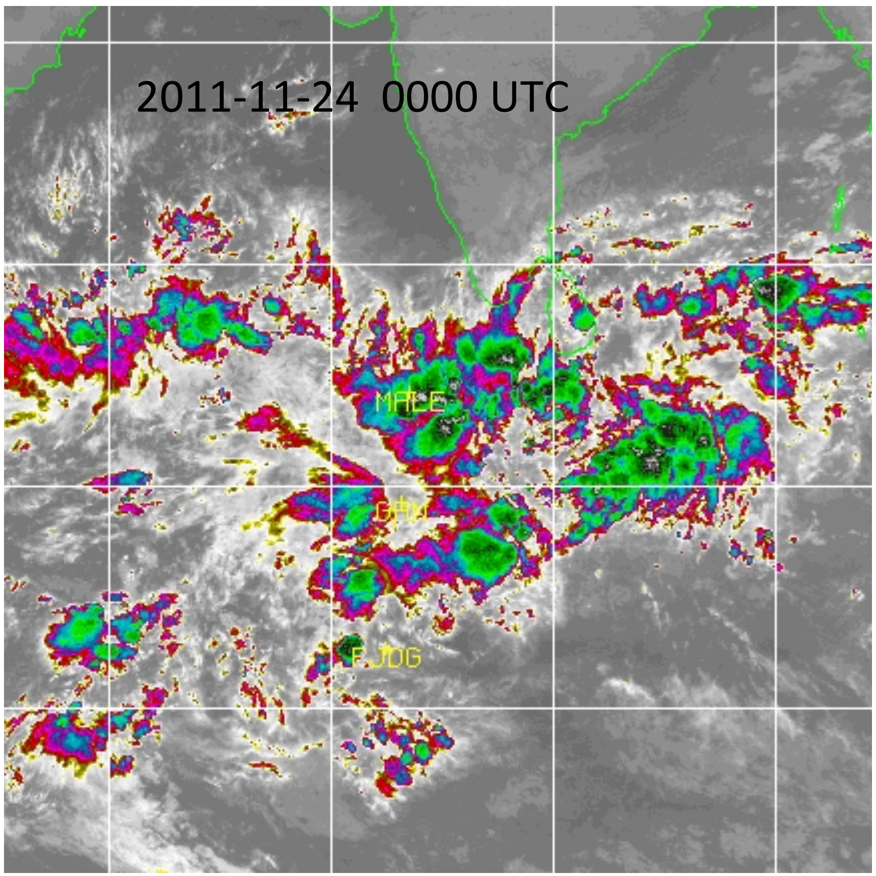


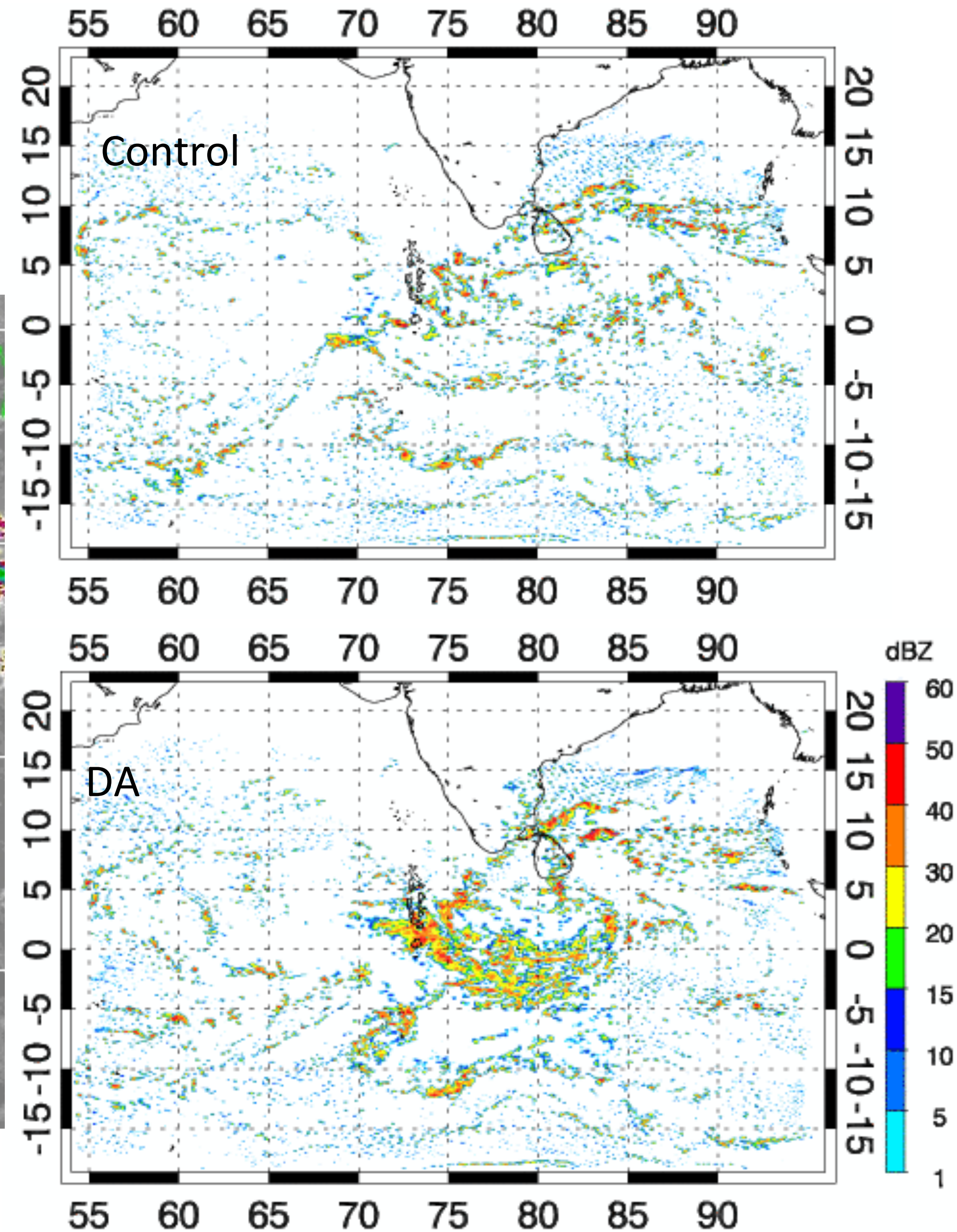
November 2011 MJO Event
Data Assimilation Plan
2011-11-24 – 2011-11-26



Meteosat IR Image vs. WRF Simulation w/ and w/o Data Assimilation

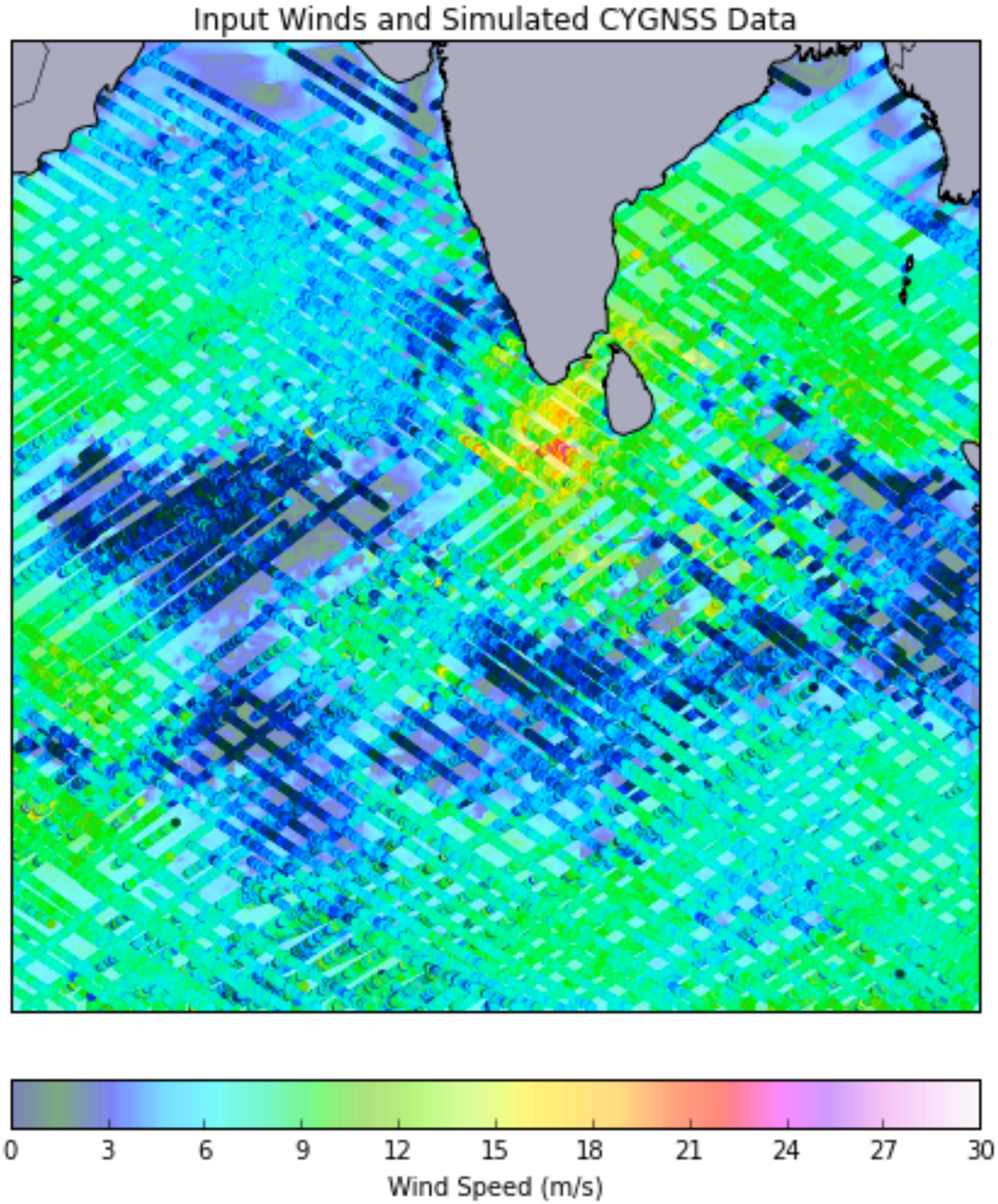
Tropical cyclogenesis and MJO genesis





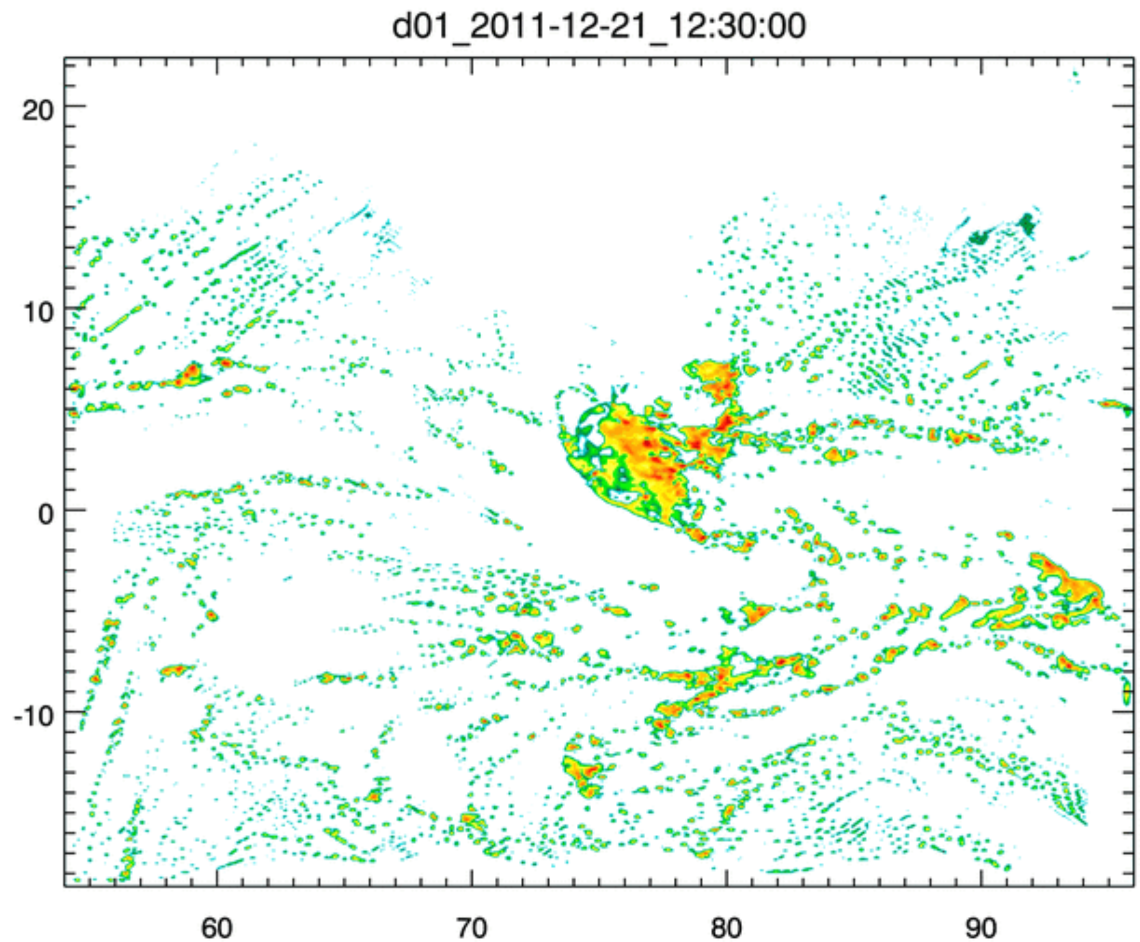
CYGNSS E2ES

- 1-second run on 11/24/11
- CYGNSS L2 winds plotted on top of WRF output wind field
- Captures enhanced winds in developing tropical cyclone
- Python module (PyGNSS)
    - Updated to Python 3 compatibility
    - NASA NTR filed
    - Need to post latest version
    - In use at MSFC/UAH

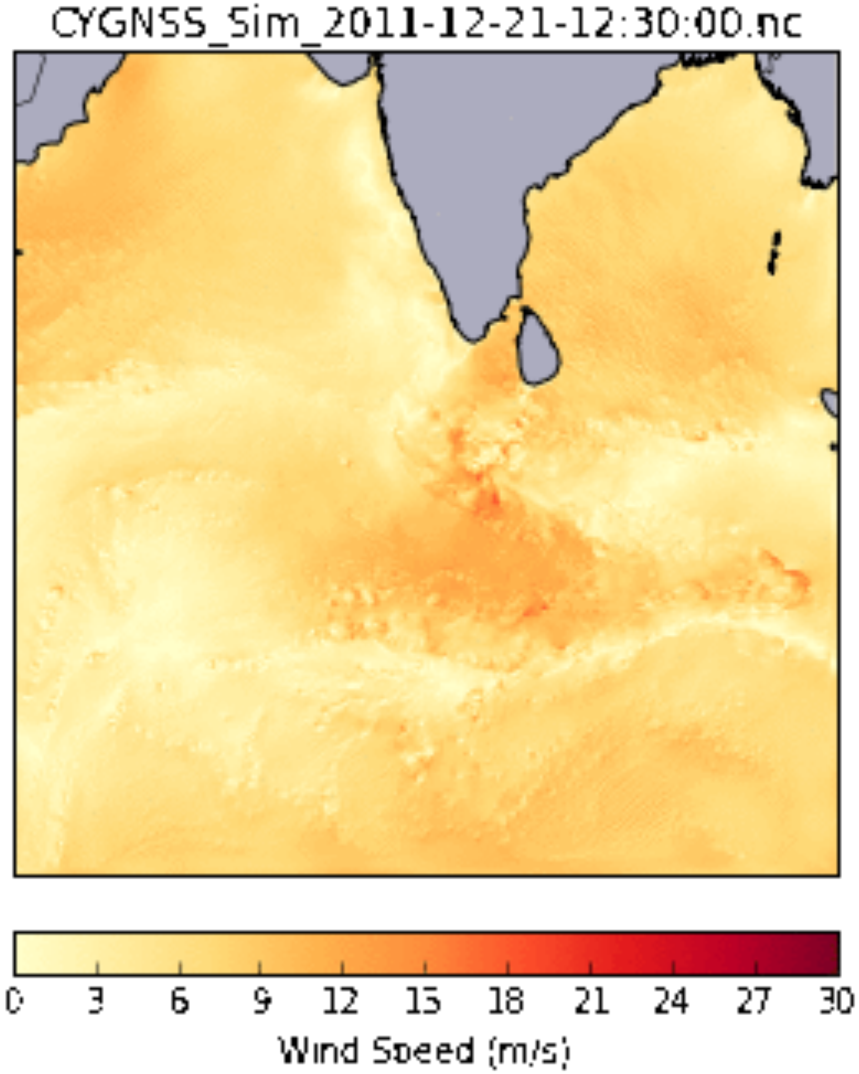


December 2011 MJO Event

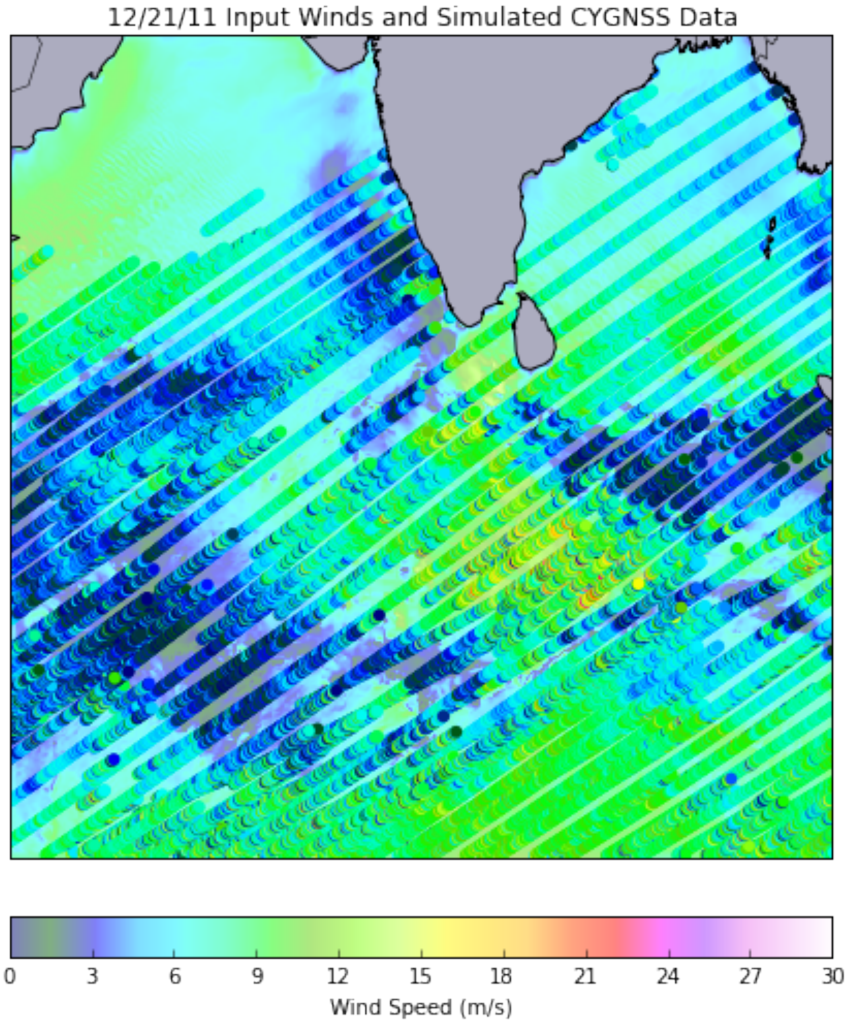
- "Mini-MJO"
- Input data: 3dvar data assimilation, 1230 UTC to 2030 UTC
- Wrfout reflectivity:

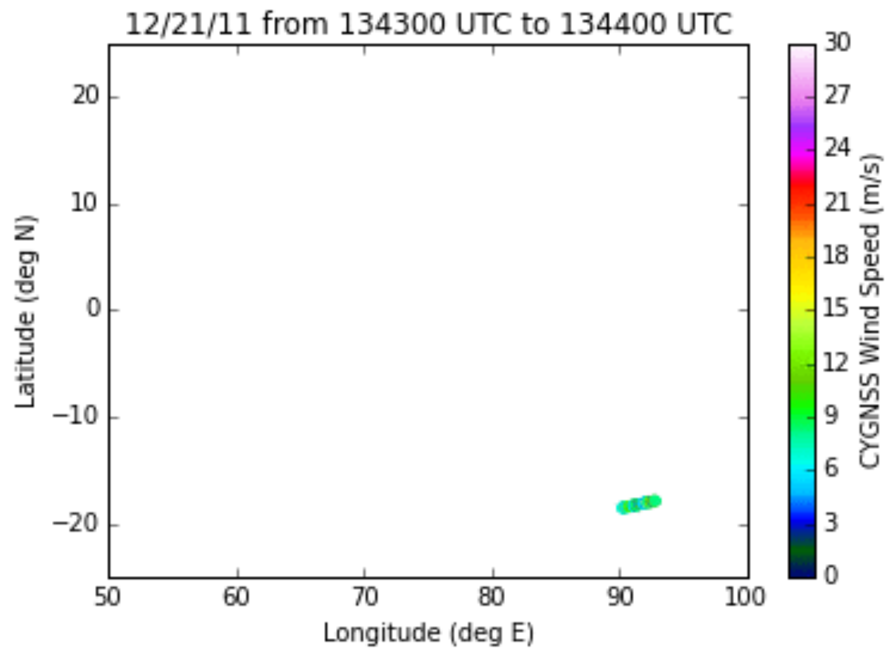


Focus on 12/21 12:30-20:30 UTC



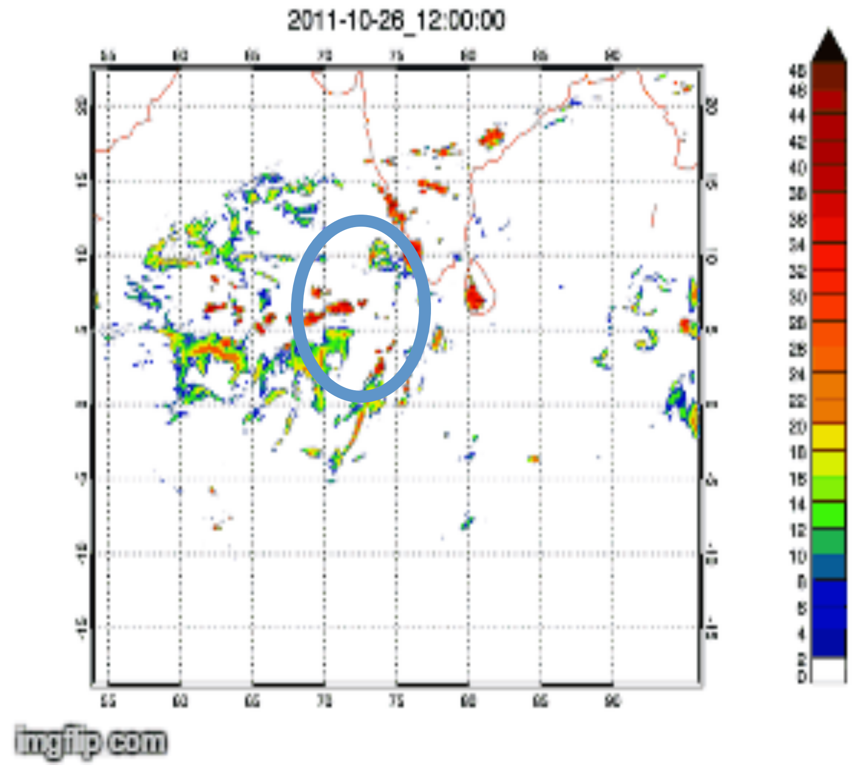
- 1 day of simulation (12/21)
- 1 second increments
- Clear MJO enhancement of winds at large scale





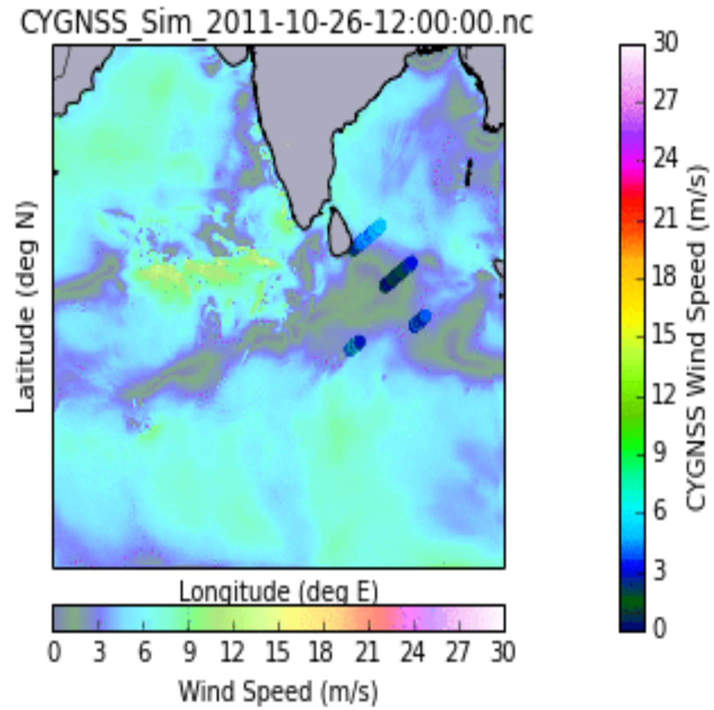
October 2011 MJO Event

- Completed WRF run assimilating TOGA radar, S-Polka radar, sounding data, buoy data, ASCAT data, OSCAT data
- Found time period with potential outflow boundary to focus on for a higher temporal resolution WRF run
  - 3 min output



End-to-End Simulator

- Ingested WRF 3 min output files from 12z to 13:54z.
- Simulation start time:
  - 12Z Oct 26 2011
- 1 second increments = 86,400 samples taken
- Had to manipulate orbit start time in order to obtain specular points over the area of interesting during the 2 hour window
- Selected orbit start time of:
  - 750z Oct 26, 2011



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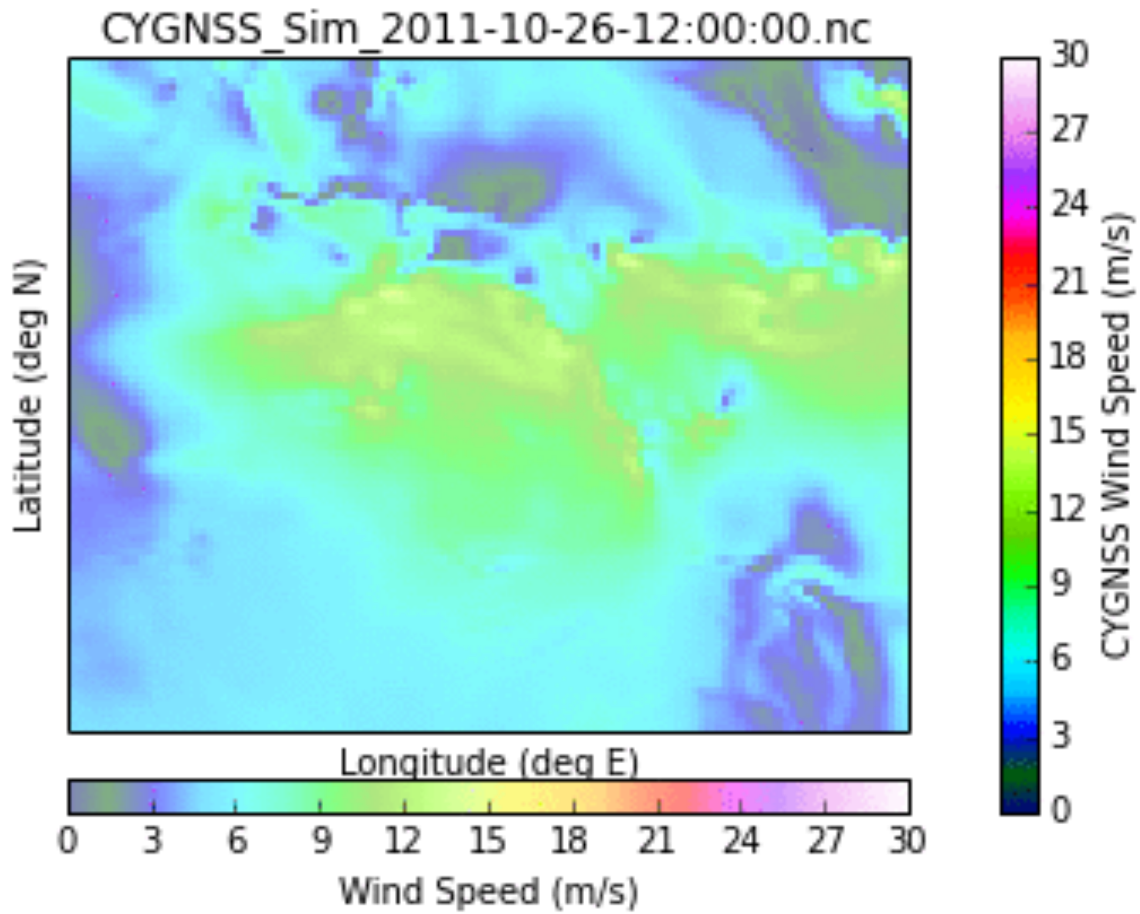
End-to-End Simulator



Summary

Three MJO onsets being investigated w/ WRF and E2ES

- November 2011 MJO
- December 2011 MJO
- October 2011 MJO

All demonstrate strong large-scale MJO signal in wind speed, which is reflected in the simulated CYGNSS observations

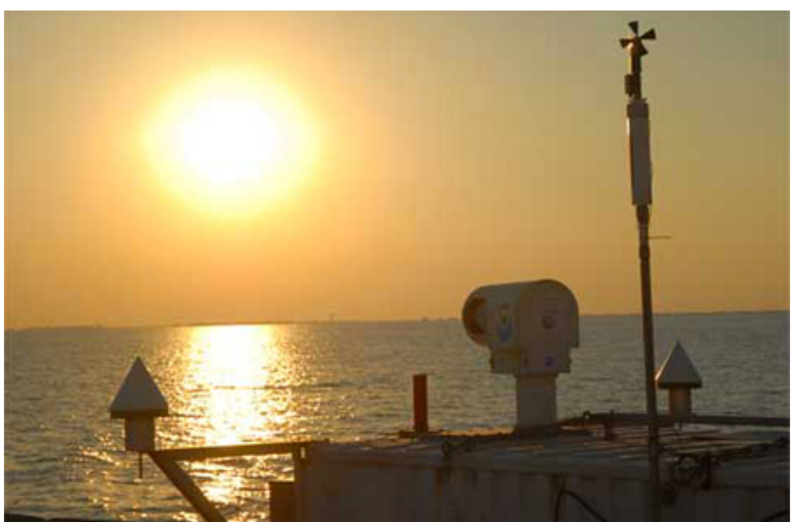
Continuing to drill down to smaller spatial/temporal scales to examine how well CYGNSS detects convective variability

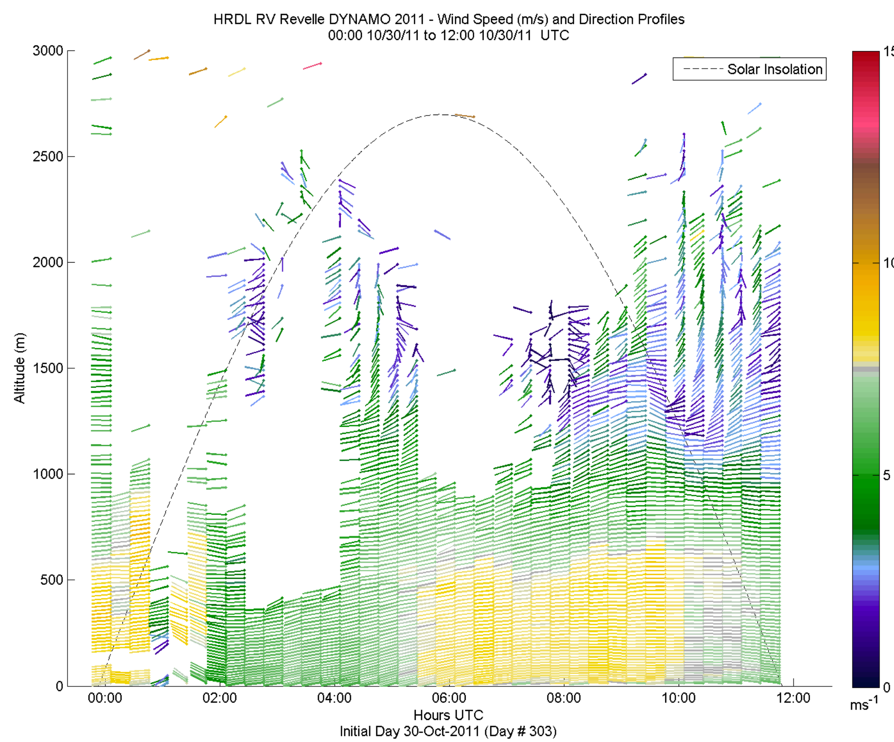
CYGNSS and Wind Power Applications

NOAA High-Resolution Doppler Lidar (HRDL)

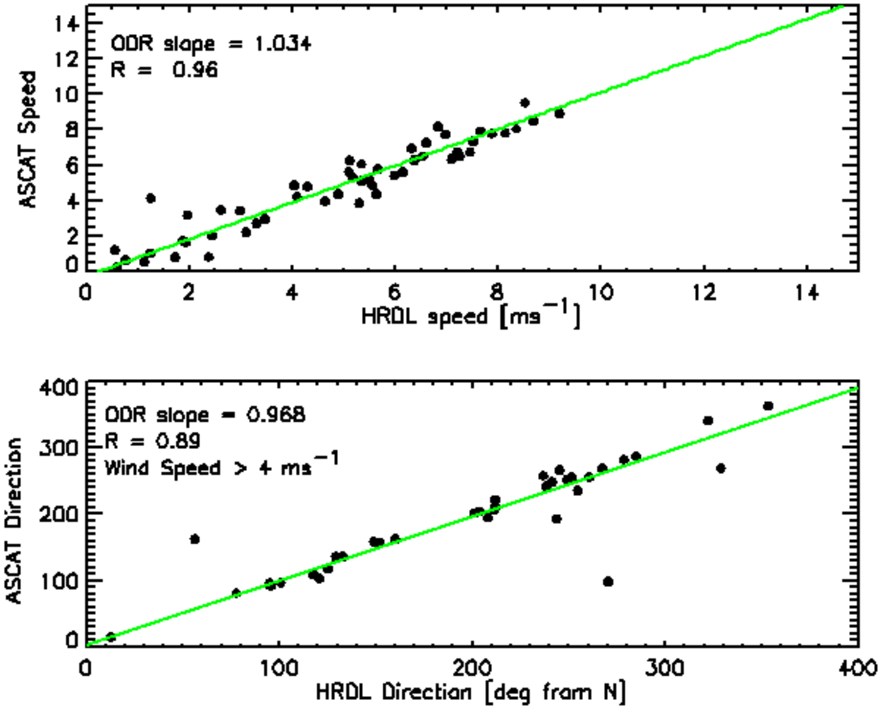
- On Revelle for Cruises 1-3 (1 September - 6 December 2011)
- HRDL scanning ability provided 20-min averaged vertical profiles of wind speed and direction from 12.5 m to ~2000 m
- 12.5-m gate used to compare HRDL to scatterometers (OSCAT and ASCAT)
- Examine relationship between winds and mean square slope as Richardson number varies

$$Ri = \frac{g\left(T_a - T_w\right)z}{T_w U_z^2},$$

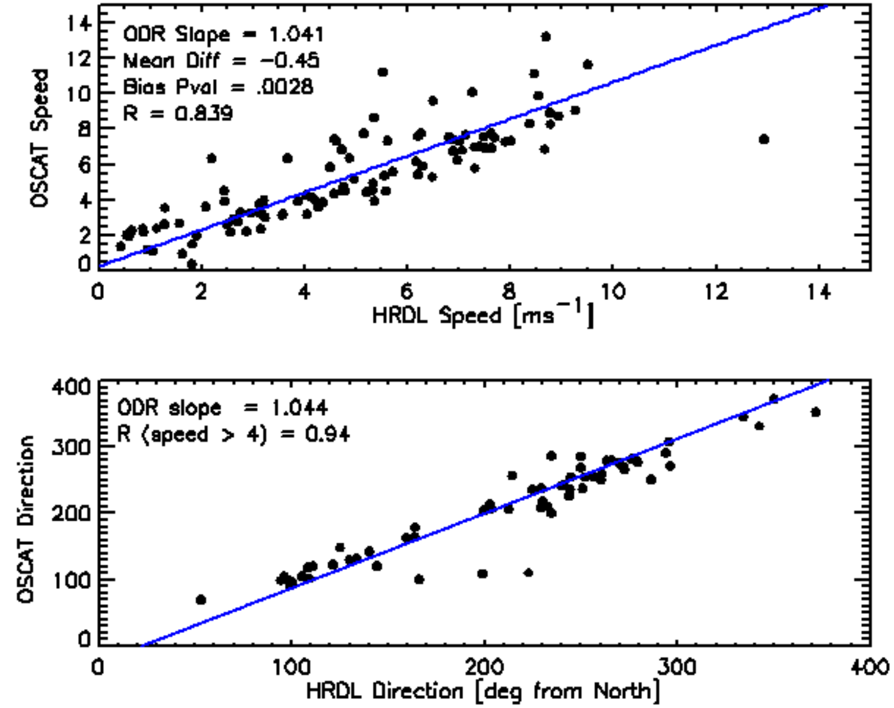




ASCAT/HRDL



OSCAT/HRDL



Lidar vs Scatterometer Statistical analysis results

	β	p-val$_{bias}$	N	m	b	p-val$_{fit}$	r
ASCAT - HRDL	0.00921	0.94	56	1.04	0.24	0.96	0.96
ASCAT - HRDL (gt 2 ms^{-1})	0.066	0.59	45	0.99	0.07	0.96	0.96

Wind Speed Bias						
	Very Unstable Mean Bias		Unstable Mean Bias		Neutral Mean Bias	
α = 0.11 in Estimated Speed	*(-100 < ri < -5)*	Number	*(-5 < ri < -0.1)*	Number	*(-0.1 < ri < 0.1)*	Number
Max Blade Height (155 m)	-1.02	381	-1.8	3020	-1.9	884
Hub Height (100 m)	-0.66	391	-0.42	3305	-0.4	949
Min Blade Height (55 m)	-1.2	389	-0.75	3228	-0.77	939
	Very Unstable Mean Bias		Unstable Mean Bias		Neutral Mean Bias	
α = 0.07 in Estimated Speed	*(-100 < ri < -5)*	Number	*(-5 < ri < -0.1)*	Number	*(-0.1 < ri < 0.1)*	Number
Max Blade Height (155 m)	-0.42	381	-1.32	3020	-1.26	884
Hub Height (100 m)	-0.34	391	-0.17	3305	-0.12	949
Min Blade Height (55 m)	-0.7	389	-0.35	3228	-0.34	939
	Very Unstable Mean Bias		Unstable Mean Bias		Neutral Mean Bias	
α = 0.03 in Estimated Speed	*(-100 < ri < -5)*	Number	*(-5 < ri < -0.1)*	Number	*(-0.1 < ri < 0.1)*	Number
Max Blade Height (155 m)	0.134	381	-0.85	3020	-0.68	884
Hub Height (100 m)	-0.027	391	0.07	3305	0.15	949
Min Blade Height (55 m)	-0.23	389	0.02	3228	0.067	939

Summary

- HRDL works well as a validation tool for scatterometer-measured winds, and can relate these near-surface winds to vertical profiles

- Using Richardson number to identify and classify wind speeds by atmospheric stability may play a role in successful extrapolation of surface wind measurements to turbine height levels

Data Assimilation and OSSE Work

Observing System Simulation Experiments

Goals:

- Determine how best to assimilate CYGNSS winds into a limited-domain, cloud-system-resolving forecast model
- Assess utility of CYGNSS observations for characterizing convective behavior during MJO onset

Table 1. Proposed sample OSSE experiments under Objective 3.

Experiment	Data Assimilation Focus	Model Domain	Horizontal Resolution
Background	N/A	2- or 3-level nested domains	12-km, 4-km (also possibly 1.333-km)
CYG	CYGNSS data	2-level nested domains	12-km, 4-km
CYG_NoRain	CYGNSS data in heavy rain areas eliminated	2-level nested domains	12-km, 4-km
CYG_OBS	CYGNSS data, basic multi-platform obs	2-level nested domains	12-km, 4-km
OBS	Basic multi-platform obs	2-level nested domains	12-km, 4-km
OBS_DYN	Enhanced obs from DYNAMO-style instrument array	2- or 3-level nested domains	12-km, 4-km (also possibly 1.333-km)
CYG_HiRes	Higher-resolution, less accurate CYGNSS data	2- or 3-level nested domains	12-km, 4-km (also possibly 1.333-km)
Obs_Err	Sensitivity exp with different observation error setup	2-level nested domains	12-km, 4-km
BG_Err	Sensitivity exp with different background error setup	2-level nested domains	12-km, 4-km

Path Forward for OSSEs

- GEOS5 Nature Run (about 7-km, 30-min res), June 2005 thru May 2007
- Accessed online via OPeNDAP, ingest into Python environment with Pydap
- Write needed variables to E2ES-compliant file via xray module
- Investigating behavior of convection/"MJO"
- WRF for forecast experiments (9-, 3-, 1-km nested grids)
- Focus on DYNAMO domain